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WARMINSTER PA 18974

SYSTEMS DIRECTORATE

TECHNICAL MEMORANDUM 20-79 3 AUGUST 1979

THE EFFECTS OF COMMUNICATIONS, COMMAND, AND CONTROL ON INTERCEPTOR EFFECTIVENESS IN ANTI-AIR WARFARE

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TECHNICAL MEMORANDUM 20-79 3 August 1979

The Effects of Communications, Command, and Control on Interceptor Effectiveness in Anti-Air Warfare

AIRTASK A360360B/001B/9F21200000

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PREFACE

This technical memorandum was prepared as part of a study being performed to develop methodology which can be applied to the quantitative analysis of communications, command, and control systems. In order to develop this analysis capability, it is first necessary to have an understanding of the ways in which the performance of the communications, command, and control system affects the capabilities of the various interfacing weapon systems. The nature of these interaction mechanisms and the relative magnitudes of their influence on force effectiveness will determine the characteristics of the needed methodology. The purpose of this technical memorandum is to define those interaction mechanisms through which the performance of the communications, command and control system affects the ability of interceptor aircraft to perform effectively in the air defense mission. These interaction mechanisms are discussed in detail, and their potential influence on force effectiveness is evaluated in representative tactical situations. These discussions are intended to provide an insight into the details of the problem that is being analyzed, and a quantitative and qualitative appreciation for the possible impacts of including these considerations in any mathematical models that are developed.

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INTRODUCTION

This technical memorandum describes the interactions which exist between C^3 (Communications, Command, and Control) performance and AAW (Anti-Air Warfare) effectiveness in a naval task force environment. This description of these interaction mechanisms is intended to provide a basis for the development of a mathematical model of air defense operations which considers C^3 effects in a realistic manner. This memorandum discusses each of the ways in which C^3 performance is believed to influence the ability of the AAW forces to perform their missions. A qualitative discussion of each interaction mechanism is provided, and, where possible, a brief quantitative illustration of the potential AAW performance sensitivity is given. Although consideration is given to all the types of weapons used in air defense, the detailed discussion concentrates on the effects of C^3 on interceptor aircraft capability since this is the area of prime interest in this study.

BACKGROUND

The influence of tactical C^3 capability on the performance of airborne weapon systems is a factor which is frequently ignored in evaluating the battle level effectiveness of naval forces. Because of the assumption of perfect C^3, most assessments of task force defensive capability are expected to be overly optimistic in view of the measures an enemy can take to disrupt current C^3 systems. Therefore, there is a need to make a realistic assessment of the effect of C^3 degradations on the ability of United States naval forces to defend themselves. In order to satisfy this need, the Naval Air Systems Command has initiated an effort to develop a methodology which quantitatively considers the relationships between C^3 system parameters and the capability of air defense weapon systems to engage and destroy enemy attackers.

In order to develop the desired methodology, the first step is to investigate the characteristics of C^3 which can have an effect on the

performance of air defense weapons. The nature of the mechanisms through which C^3 interacts with each weapon system must then be determined so that appropriate mathematical relationships can be derived. This technical memorandum presents the results of the initial phase of the study to perform the above tasks.

OBJECTIVES

This memorandum presents a general discussion of the interaction mechanisms through which C^3 is believed to influence the air defense effectiveness that can be achieved by a naval task force. The contents of this memorandum are intended to serve a number of purposes. First, they explain the specific nature of the problem which is being analyzed. This is important since C^3 is not well understood by many people, and the impact of C^3 on task force operations is not always fully appreciated. The second objective of this memorandum is to provide a checklist against which one can measure the capabilities of any methodology. The various interaction mechanisms which will be discussed are candidates for consideration in any model of C^3 operations in an air defense environment. The extent to which any given interaction must be considered by a model will depend on the sophistication of the rest of the model and the importance of the specific interaction. The discussions of C^3/AAW interactions presented here are intended to allow the reader to put these factors into perspective outside the structure of any specific methodology. Finally, the memorandum provides a basis for detailed discussions on C^3 effectiveness measurement, and a preliminary comparison of the magnitude of various C^3 effects in AAW operations.

REPORT OVERVIEW

The next section in this memorandum provides an overview of C^3 in general and briefly discusses some potential limitations in C^3 performance. The potential effects of C^3 deficiencies are also summarized. The section after that analyzes each of the effects that C^3 performance

can have on interceptor aircraft. It provides both qualitative and quantitative assessments of the mechanisms by which the performance of the C^3 system affects the capability of interceptor aircraft to perform their mission. The final section summarizes the results of these investigations.

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COMMUNICATIONS, COMMAND, AND CONTROL

Command and control can be defined as follows (reference (a)):

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of his mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures which are employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of his mission.

At the tactical level of anti-air warfare, the C^3 system includes any of the above elements which the OTC (Officer in Tactical Command) or his designated representatives use to gather necessary information, to aid in decision making, and to direct the activities of the defensive forces. Although the actual sensors used to detect and track the threat are not always included in the C^3 system, most of the activity occurring aboard sensor platforms such as the E-2C is considered to be C^3 related. At all of its interfaces with the rest of the force, the line separating the C^3 system from the sensors, weapons, and other systems of the force is not always a distinct one. However, for purposes of this study, the C^3 system is assumed to include:

- all of the equipment and personnel that interpret sensor outputs
- all of the equipment and personnel that maintain an awareness of the status of all the units (friendly, enemy, neutral) of interest in the AAW problem
- all of the equipment and personnel involved in processing and displaying the above generated data, and the decision makers using the data
- all of the equipment and personnel involved in transferring tactical data/information from its origin to its destination

C^3 DEFICIENCIES

A perfect C^3 system would collect all the available data bearing on a particular problem and deliver that data, properly correlated, to a decision making element in a form that would allow it to be used effectively. The decision making element would employ this information to reach some optimized decision and then it would transmit appropriate data to any elements affected by the decision. All of this would be accomplished in some amount of time which would not reduce the effectiveness of the response from its optimum value.

Clearly, there are a very large number of factors which can cause any C^3 system to operate less than perfectly. Communications can be imperfect due to propagation problems, equipment deficiencies, lack of connectivity, operator or channel overloading, enemy countermeasures, or other factors. Data needed to make a correct decision may not be provided to the decision maker due to storage limitations, lack of adequate data processing speed, display deficiencies, etc. The decision maker may be overloaded and unable to reach a timely decision in an imperfect C^3 system. Finally, the system may not properly distribute data needed to carry out a given decision in a coordinated fashion due to any of the above-mentioned factors.

Any individual or combination of the above problems can result in a level of C^3 performance which is reduced from that provided by an ideal system. For example, if a search radar detects an incoming aircraft, but the operator has difficulty reporting the contact because the proper communications channel is busy, there may be a delay in the initiation of a response to the potential threat. If that delay is sufficiently long, the C^3 problem "necessary communications not available" could cause a reduction in task force defensive capability. Similarly, if the above contact is reported in a timely fashion, but the decision maker is unaware of the fact that a weapon system is already assigned to engage the threat, he may divert other assets to counter the perceived threat.

If these assets are needed elsewhere, the C^3 problem "lack of current status on own forces" will result in reduced force effectiveness. In each case, an ideal C^3 system would have made optimum use of available resources in a minimum amount of time.

In this technical memorandum, there is no attempt to consider individual C^3 deficiencies such as those mentioned in the previous paragraph. Because of the large number of specific types of problems that could be encountered, and their dependence on the exact structure of the C^3 system under consideration, it is impossible to treat each degradation factor individually. Instead, two general classes of C^3 system deficiencies are discussed. These two problem areas are (1) delays, and (2) errors, which can be attributed to the C^3 system. Any time-consuming function which a C^3 system performs (for example, computing the proper intercept heading to use in a vectoring command) is equivalent to introducing a delay in the final C^3 action. Since many C^3 functions are performed in sequence, the addition of a large number of small delays could result in a substantial time delay in some military action. More importantly, if the enemy takes actions such as communications jamming to aggravate the delay in transmitting critical data from one place to another, the effect on the outcome of a given battle may be very large. In addition, since many C^3 functions involve the transfer, display, and assessment of data and information, there is always the possibility that an error will be introduced into the data/information. If in reporting some target's position, an element of the C^3 system introduces an error, the force may react to the threat in an entirely inappropriate manner. A similar effect could be experienced when the wrong identification is attached to a target track. In each case, an error introduced by some deficiency within the C^3 system can cause a reduction in force effectiveness relative to what would be experienced with a perfect C^3 system.

Because of the above factors, C^3 deficiencies which are considered as causes for reduced force effectiveness in this memorandum are:

1. the introduction of time delays within the C^3 system
2. the introduction of errors into information flowing within the C^3 system

These two causes will bring about certain effects in the way force elements are employed in any given tactical situation. The next section presents the effects that are considered likely to be important in terms of a force's air defense capability.

EFFECTS OF C^3 DEFICIENCIES

In a given tactical situation, when the performance of the C^3 system is in any way degraded from perfect operation, there will be a number of different effects that may be experienced. These are effects on the actions of the defensive weapons systems which may ultimately result in a reduction in force effectiveness. This section describes the various effects on the defensive systems which can be brought about by C^3 deficiencies. Separate discussions are provided for effects on interceptor aircraft, SAM (Surface-to-Air Missile) systems, and EW (Electronic Warfare). The purpose of this section of the memorandum is to briefly define these various effects on the weapons systems. A detailed analysis of the cause-effect relationships is contained in the next section.

Effects on Interceptor Aircraft

Wherever the tactical C^3 system introduces a delay or an error into the information required by the force to counter a threat using interceptor aircraft, there are 10 possible effects that this may have. In general, these effects may occur individually or in combination, and they may or may not influence the overall defensive effectiveness. Table 1 presents a summary of these potential effects on interceptor

TABLE 1. EFFECTS ON INTERCEPTOR AIRCRAFT OF DEGRADATIONS IN C^3 PERFORMANCE

1. Late initiation of interceptor flyout
2. Suboptimum allocation of interceptors to targets
3. Interceptor flies out in wrong direction
4. Interceptor flies out on non-optimum path
5. Interceptor flies out too slowly
6. Interceptor flies out too fast
7. Interceptor not properly positioned to engage targets
8. Interceptor engages non-optimum target
9. Interceptor delays in engaging target
10. Interceptor fails to complete an engagement

aircraft. The following paragraphs briefly describe each of these effects.

1. Late Initiation of Interceptor Flyout

This effect is defined as a delay in the time that an interceptor aircraft starts flying out to engage a threat. The flyout delay may be due to the fact that the C^3 system is late in providing the initial command or the failure of the interceptor pilot to act on available information. During the delay, the interceptor will normally fly its assigned loiter pattern at the CAP (Combat Air Patrol) station or remain on the aircraft carrier deck awaiting launch.

2. Sub-Optimum Allocation of Interceptors to Targets

The pairing of interceptors and targets is one of the major functions of the C^3 system. To achieve the proper allocation of interceptors to targets, the C^3 system should know the nature of the threat which is to be countered and allocate resources accordingly. Whenever the C^3 system is not able to assign the proper number of interceptors against each of the target groups, the total number of kills achieved by the interceptor force may be reduced.

3. Interceptor Flies Out in Wrong Direction

When an interceptor starts flying out in a direction which cannot result in a successful intercept, the aircraft can be defined to be flying out in the wrong direction. The interceptor fly-out will be terminated when the C^3 system or the interceptor realizes that there is no valid target to be engaged, or when the interceptor reaches his endurance limit. Although this problem may be the result of a well-executed enemy feint, it is the function of the C^3 system to prevent this from occurring or at least to minimize the severity of the problem.

4. Interceptor Flies Out on a Non-Optimum Path

When an interceptor is assigned to engage a target, the path that it flies from its initial position to the final intercept is ideally a collision course with an appropriate offset point. Any deviation from a collision course can result in the expenditure of additional time and fuel to reach the target. This problem can be caused by errors in the command heading and speed provided to the interceptor by the C^3 system. The result of this is that the interceptor reaches the location of the target later than it would if it had flown an optimum path, and it also has less fuel on board when it reaches the target.

5. Interceptor Flies Out Too Slowly

When the C^3 system has an inaccurate perception of the tactical situation, it may instruct an interceptor to fly out at too slow a speed to achieve a successful intercept. This effect may also result from an error being introduced in the command data received by the interceptor. In any case, this will cause the interceptor to reach its intercept position later than if it had received the proper command speed. This may result in a missed intercept or in the intercept occurring too late to be effective.

6. Interceptor Flies Out Too Fast

When the C^3 system's perception of the tactical situation is in error, it may instruct an interceptor to fly out at too high a speed. This effect can also result from the interceptor receiving an incorrect command speed. When this occurs, the interceptor will accelerate to too high a speed, thereby using an excessive amount of fuel. The high flyout speed can cause the interceptor to reach the threat too early and interfere with an attack by another interceptor, or the interceptor may have to terminate the intercept due to a low fuel state prior to engaging the target.

7. Interceptor Not Properly Positioned to Engage Targets

During the initial phase of an air-to-air intercept, the interceptor aircraft will be receiving altitude, speed, and heading commands from the C^3 system. These commands will be dependent on the threat data available to the C^3 system, and will be constantly updated based on the latest information on the interceptor's and the threat's position and velocity. As the interceptor and the threat close on one another, the vectoring data is intended to place the interceptor in an optimum position to detect and begin its engagement of the threat. However, if the vectoring data is imperfect, the final positioning of the interceptor when it detects the threat and initiates its attack may not be optimum. This will result in the interceptor's maneuvering to achieve a good tactical position against the threat. If it is not able to achieve the proper position, the kills which can be inflicted by the interceptor may not be as high as might have been obtained under other circumstances.

8. Interceptor Engages Non-Optimum Target

When an interceptor aircraft reaches a position where it can detect the threat against which it has been assigned, it may or may not recognize the specific targets which it has been ordered to engage. This will depend upon the accuracy of the vectoring and the information which the interceptor has about the threat. If the C^3 system does not define an optimum target for the interceptor to engage, or if it does make that selection but cannot accurately transmit these data to the interceptor, there is a possibility that the interceptor will engage a non-optimum target. This situation could result, for example, when two interceptors assigned to engage two separate but nearby targets both engage the same target.

9. Interceptor Delays in Engaging Target

When an interceptor detects its assigned target on its AI (Airborne Intercept) radar, it begins preparations to engage that target. When

optimum engagement range is reached, the interceptor should begin attacking the target. If anything interferes with the sequence involved in engaging the target, the interceptor may delay in initiating the engagement. The delaying factors could be uncertainty as to the identity of the target, uncertainty as to which specific target is to be engaged, or the knowledge that some other friendly asset is in the vicinity and may accidentally be engaged. It is the responsibility of the C^3 system to provide the interceptor with the information needed to prevent this problem.

10. Interceptor Fails to Complete an Engagement

Once an interceptor has initiated an engagement against a target or a group of targets, it will generally attempt to maximize performance by carrying the engagement through until it has exhausted its ordnance or killed the targets. However, in certain situations, the interceptor may improperly break off the engagement prior to achieving maximum effectiveness. This can occur when the interceptor is uncertain as to the possibility that the target may be about to be engaged by some other friendly weapon system. In this situation, the interceptor has not achieved its full potential kill capability due to the failure of the C^3 system to make necessary information available to the interceptor in a timely fashion.

Effects on SAM Systems

When the C^3 system directing the use of SAM systems against an air threat introduces any time delay or error into the commands or coordination directives issued to the SAMs, there are four effects which are possible. These effects may occur individually or in combination, and may or may not affect the outcome of the engagement depending on the specifics of the situation. Table 2 summarizes the potential effects of C^3 deficiencies on SAM systems. The following paragraphs define each of these effects in greater detail.

TABLE 2. EFFECTS ON SAM SYSTEMS OF DEGRADATIONS IN C^3 PERFORMANCE

1. Delay in launch of SAM
2. Engagement of a non-optimum target
3. Improper selection of firing doctrine
4. Early termination of an engagement

1. Delay in Launch of SAM

In order to maximize the number of targets that can be engaged by a SAM battery, it is desirable that threats be taken under fire as early as possible. When deficiencies in the C^3 system cause delays in the assignment of a SAM battery to a target, or when errors in available data make it difficult for the SAM system to perform necessary functions such as target acquisition, there may be a time delay in the launch of a SAM against the target. This can result in a reduction in the expected number of kills achieved by the SAM system against an air raid. The reduction in expected kills will be due to the decreased time during which the enemy is exposed to the SAM system.

2. Engagement of a Non-Optimum Target

When multiple targets are available to be engaged by one or more SAM batteries, problems in the operation of the C^3 system can result in one or more of the SAMs engaging a non-optimum target. A non-optimum target would be one which the C^3 system should know is of lower priority than some other unengaged target. A typical example of this is when one SAM battery engages a target that is also being engaged by another battery. This can happen whenever communications difficulties are experienced or when the weapon assignment function does not take advantage of all tactical data available within the C^3 system. Because of these types of C^3 problems, the expected kills achieved by the SAM systems may be reduced, or the number of missiles expended to counter an air raid may increase.

3. Improper Selection of Firing Doctrine

The decision on whether a SAM fire unit should use a fire-assess-fire or a fire-fire-assess-fire doctrine when engaging a specific target depends on many tactical factors. These include target priority,

remaining missile inventory, and potential target reengagement opportunities. Although this decision is frequently a matter of "standard operating procedures," the C^3 system should have the necessary data to optimize this choice as an engagement proceeds. However, when delays or errors are introduced into C^3 actions, the ability of the C^3 system to effectively control this engagement parameter will decrease. When compared to an optimum strategy, this will result in some reduction in expected kills achieved or the wasteful expenditure of missiles.

4. Early Termination of an Engagement

Once a SAM system has taken a target under fire, it can be expected to continue the engagement until the target is killed or it has left the system's field of fire. However, it is possible that through some error or confusion introduced by the C^3 system, the SAM battery may incorrectly terminate the target engagement prior to killing the target. When this occurs, there is an increase in the probability that the threat will survive to penetrate the task group vital area.

Effects on Electronic Warfare

C^3 system deficiencies will also affect the employment of electronic warfare in air defense operations. Three major effects that may occur are summarized in Table 3. The following paragraphs provide a more complete definition of each of these effects.

1. Late Initiation of ECM

The decision to employ ECM (Electronic Countermeasures) against an inbound threat will generally be based upon data provided by the C^3 system. When the C^3 system introduces delays or errors into data which impacts that decision, it may result in a delay in the use of the countermeasure. Under certain conditions, this delay may be adequate to allow the threat to perform its mission despite the presence of the

TABLE 3. EFFECTS ON ELECTRONIC WARFARE SYSTEMS OF DEGRADATIONS IN C^3 PERFORMANCE

1. Late initiation of ECM

2. Use of wrong ECM technique (does not produce desired result)

3. Use of ECM that interferes with some other friendly system

countermeasures. The C^3 deficiency is therefore ultimately responsible for a decrease in force defensive capability.

2. Use of Wrong ECM Technique

The selection of the ECM technique which will be used to counter a particular threat can be affected by the availability of appropriate data within the C^3 system. When such data exists within the C^3 system, but is delayed or not used, the ECM selected may be a technique which is not effective against the particular threat involved. For example, noise jamming might be employed against a threat with a known home-on-jam capability, whereas an appropriate deceptive ECM technique could have been selected if the C^3 system had made the proper target identification available to the jamming platform. This situation results in a reduction in force defensive capability relative to what could be achieved with proper C^3.

3. Use of ECM That Interferes With Some Other Friendly System

The C^3 system is generally the mechanism that provides for coordinated use of force weapons. When the C^3 system is not functioning in an optimum manner, it may permit uncoordinated actions which cause mutual interference among weapon systems. This is especially true for ECM. Energy radiated to counter one threat could degrade the performance of a sensor or weapon needed to counter some other threat. The ability to prevent this depends on proper planning and the timely availability of appropriate data within the C^3 system. When the C^3 system allows this type of interference to occur, there will typically be a reduction in the defensive effectiveness of the force.

ANALYSIS OF INTERACTION MECHANISMS

The previous section of this technical memorandum discussed the ways in which C^3 performance may be degraded, and grouped these into two general C^3 deficiencies. These deficiencies are (1) the introduction of time delays into the C^3 process, and (2) the introduction of errors into the data on which C^3 depends. These C^3 deficiencies are potentially the cause of a large number of problems encountered in achieving maximum effectiveness with available weapon systems. For the three principal types of weapon systems involved in air defense, the previous section also defined the various effects which can be attributed to degraded C^3. This section discusses the cause-effect relationships which are believed to exist between C^3 deficiencies and reductions in weapon system effectiveness. The interaction mechanisms through which C^3 performance capability influences specific aspects of weapon system actions are described and analyzed. Where possible, the relationships are quantified to illustrate the nature of the interaction in specific terms. However, at the present time, this cannot be done in a detailed fashion for all the interaction mechanisms. Also, since current efforts are focused on the relationships between C^3 and interceptor aircraft employment, only these interactions are described.

The interaction mechanisms through which C^3 is coupled to interceptor aircraft effectiveness are discussed under the general headings of the effects on interceptor aircraft actions as presented in the previous section. The ways in which C^3 delays and C^3 errors bring about the listed effect are discussed first, and then a quantitative example of the interaction is presented where possible.

LATE INITIATION OF INTERCEPTOR FLYOUT

When an event occurs which requires a response by an interceptor aircraft, any time delay within the C^3 system can cause a delay in the initiation of CAP or DLI (Deck Launched Interceptor) flyout towards the

threat. This delay may result in the intercept occurring later than it otherwise would, or in a missed intercept. A variety of errors which occur within the C^3 system may also result in the late initiation of interceptor flyout. These include the misidentification of a target or provision of low quality tracking data which may cause the AAWC (Anti-Air Warfare Coordinator) to believe that an intercept is not required. At some later time, additional data or a correction of the initial error may lead to a decision to initiate interceptor flyout. The error in this case has caused a late initiation of the interceptor flyout. The effect is equivalent to the introduction of a delay within the C^3 system. Any delay that causes an interceptor to get a late start in flying out towards the threat will adversely affect its ability to perform its mission and so reduce expected air defense effectiveness.

When interceptor flyout is delayed, its influence on air defense effectiveness will be dependent on the specific tactical situation. No general relationship between flyout delay and interceptor effectiveness can be defined. It should be noted, however, that any given C^3 delay will result in approximately one-half as much delay in the time the intercept is achieved. The exact value will depend on the geometry and the target and interceptor speeds. In a typical situation with a target and interceptor speed of 500 knots, a C^3 delay of 5 minutes in initiating interceptor flyout will cause the intercept to be delayed 2.5 minutes relative to what would have occurred if there had been no C^3 delay. This means that the target penetrates 20.8 nmi closer to the force before it is intercepted. This may or may not translate into a tactical advantage for the threat aircraft.

SUB-OPTIMUM ALLOCATION OF INTERCEPTORS TO TARGETS

One of the major functions of the C^3 system in AAW is to allow the AAWC to arrange for an optimum allocation of his resources against the threat. Although the information needed to actually optimize the use of resources is not always available within the C^3 system, the more information

about the threat that the AAWC has, the better he can use his assets. When delays within the C^3 system prevent critical information from reaching the AAWC, he may assign too many resources against part of the threat and too few against some other part. If this cannot be corrected, it will result in a reduction in the effectiveness of the defensive effort. Since the flexibility to reallocate forces will generally decrease as a function of time, the longer critical information is delayed within the C^3 system, the greater is the expected loss in effectiveness. The actual rate at which effectiveness decreases as a function of time delay is dependent on the detailed scenario.

The introduction of errors into tactical data can also result in suboptimum allocation of interceptors to targets. If raid size is not accurately reported to the AAWC, the number of interceptors assigned to engage a raid may be more or less than is needed to counter the threat. In either case, this can have a serious degrading effect on defensive capability. Navigation errors frequently cause the multiple reporting of individual tracks, and when this is allowed to propagate through the C^3 system, the effect is an error in raid assessment. If more interceptors are dispatched to engage the raid than are actually needed to kill the available targets, valuable defensive resources have been wasted. This is especially true when multiple raids occur simultaneously and a limited number of interceptors are available to engage them.

To illustrate the potential effectiveness impact of this problem, consider the following situation. Assume that two air raids are approaching a task force, one raid containing 24 aircraft and the other containing 4 aircraft. Also assume that the AAWC has 8 interceptors available at task force center that can intercept the raids. If the AAWC's knowledge of the raid sizes is accurate and timely, his probable allocation of assets would be 2 interceptors against the 4 plane raid and 6 interceptors against the 24 plane raid. If each interceptor carried 4 missiles with a kill probability of 0.8, one would expect the interceptors to kill 3.84 targets in the 4 plane raid and 19.2 targets in the 24 plane raid for a total attrition of 23.04 aircraft, as shown in

Figure 1. However, if the C^3 system provided the AAWC with no raid size information, his probable resource allocation would be 4 interceptors assigned against each raid. In this case, the expected results would be 3.99 targets killed in the 4 plane raid and 12.8 targets killed in the 24 plane raid as shown in Figure 2. The total attrition of 16.79 aircraft is a 27% reduction in effectiveness relative to the case of better resource allocation. This means that C^3 performance can have a substantial influence on air defense effectiveness. The above conclusion remains true even if a much less effective air-to-air missile is assumed. If the missile kill probability is assumed to be 0.4 instead of 0.8, the better resource allocation still gives an expected attrition of 12.16 compared to 9.88 for the assignment of 4 interceptors against each raid. This means that degraded C^3 can result in a 19% loss in effectiveness.

INTERCEPTOR FLIES OUT IN WRONG DIRECTION

In certain situations, an interceptor may begin flying out, either autonomously or under C^3 system orders, in a direction which cannot result in an effective intercept. The action may be the result of a C^3 error, an enemy feint, or some set of coincidental events which indicate the need for a response. Under any of these conditions, information which indicates that the interceptor should be recalled will become available to the C^3 system at some specific point in time. If the interceptor is then recalled and returns to a CAP station, its utility in countering another threat is reduced due to the lower fuel reserves that the interceptor now has on board. If a new threat is detected while an interceptor is still flying out in the wrong direction, the interceptor's ability to counter the threat is reduced not only by the fuel wasted but also by any extra distance that the interceptor must fly to reach the threat. Through these mechanisms, C^3 system deficiencies which allow an interceptor to fly out in the wrong direction have an adverse impact on air defense effectiveness. Note that when the initial flyout decision was based on a well-executed enemy feint or some other valid reason, the reduction in force effectiveness is not the fault of

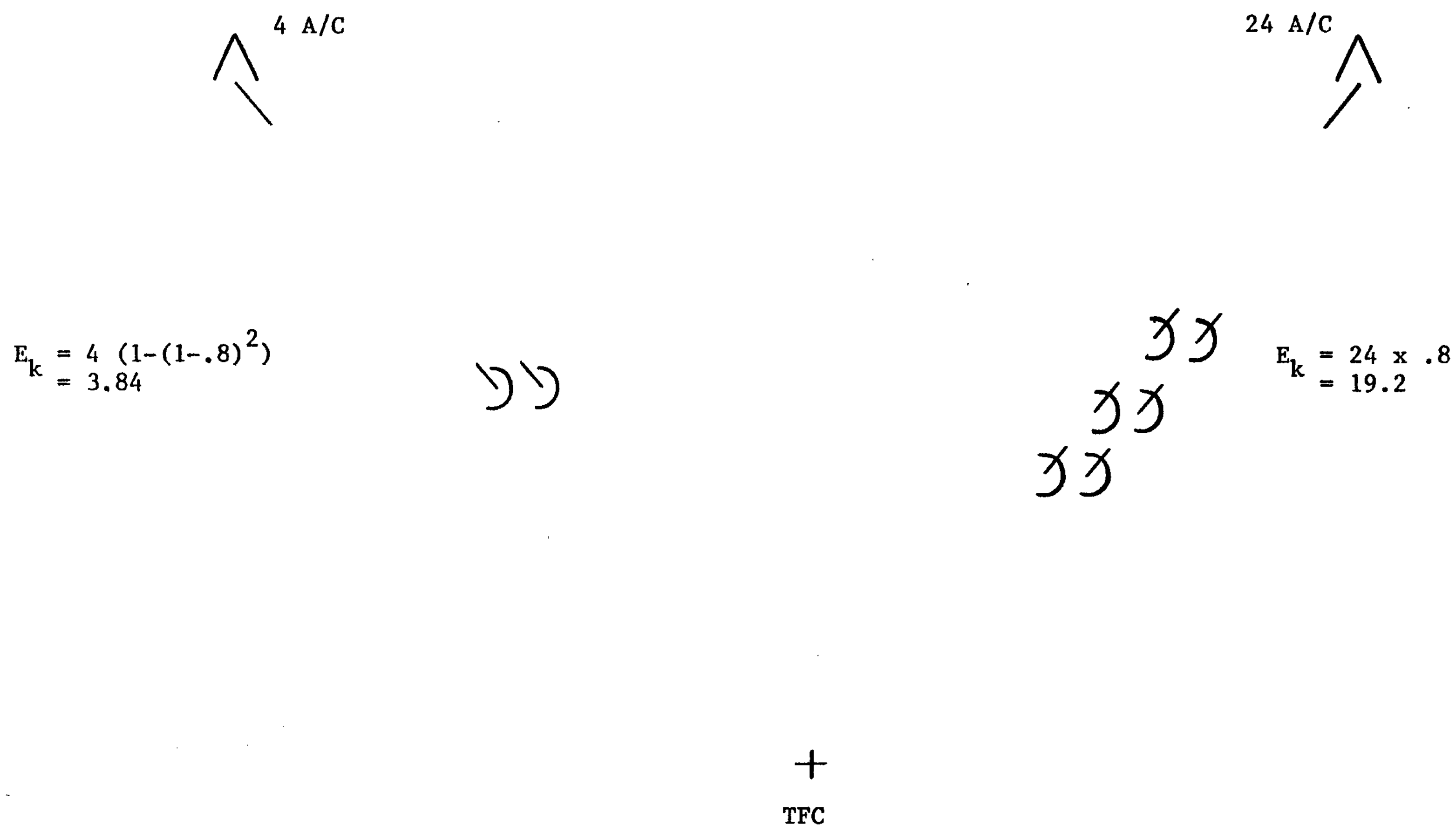

Figure 1. Air Defense Effectiveness - Optimum Interceptor Allocation

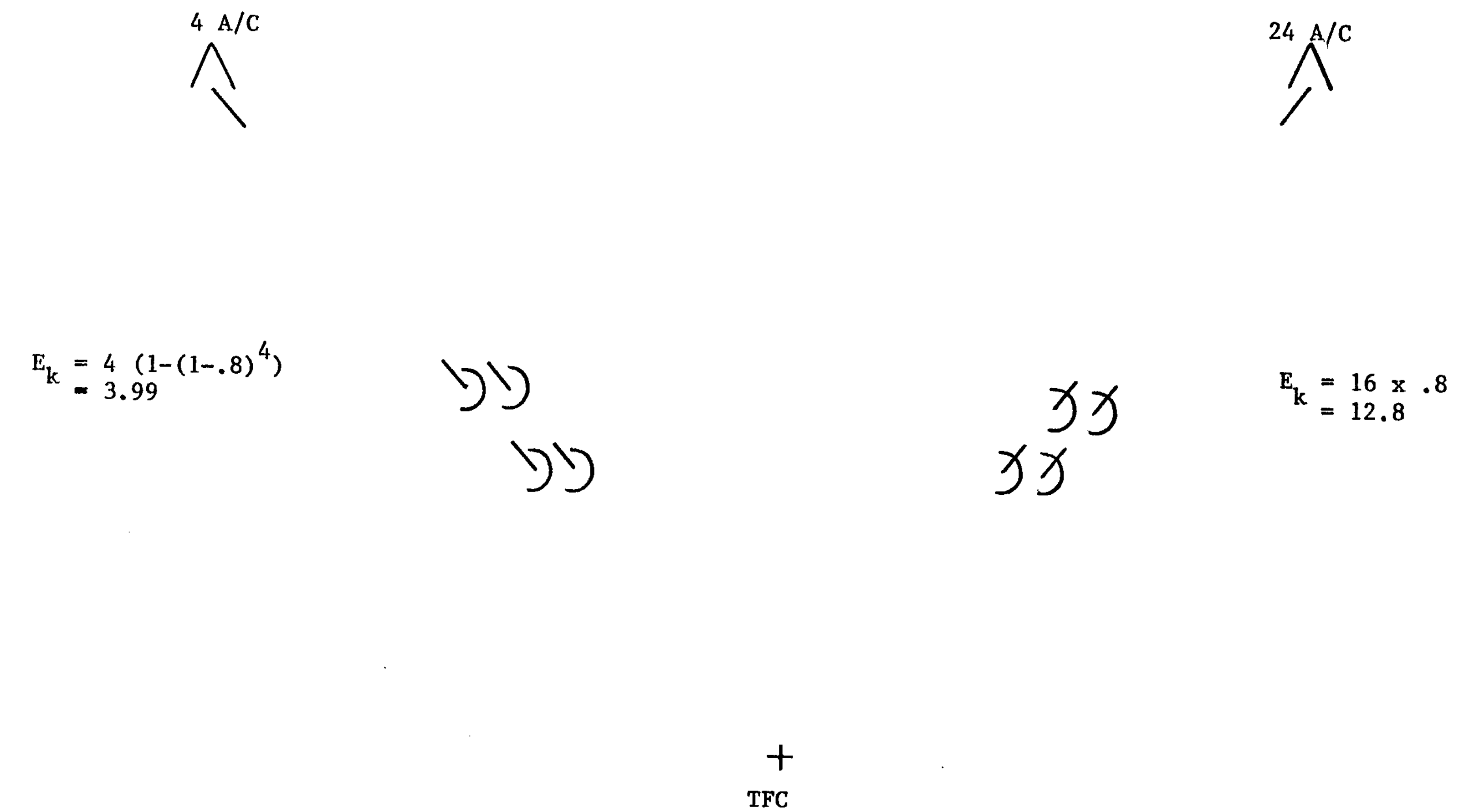

Figure 2. Air Defense Effectiveness - Sub-Optimum Interceptor Allocation

the C^3 system. If, on the other hand, the C^3 system makes an error and fails to recall the interceptor, or introduces a delay into the recall action, there is a loss in force effectiveness which can be attributed to a deficiency in the C^3 system.

An example of this situation is presented in Figure 3. The interceptor at CAP station A is ordered (due to a C^3 system error) to intercept the target at location B. When the interceptor reaches location C, the C^3 system recognizes its error and orders the interceptor to change course and fly out to engage the threat just detected at position D. If the interceptor is able to engage the threat, the engagement will be delayed due to the extra distance the interceptor must fly (from C back to A) and the interceptor will arrive at the point of attack with a reduced fuel reserve compared to what would have occurred if the C^3 system had held the interceptor at the CAP station.

Several types of C^3 deficiencies can cause or aggravate this problem. They include all types of errors in initial threat localization or evaluation which result in the C^3 system initiating interceptor flyout when the situation, if properly interpreted, does not call for this action. Once flyout has begun, any delay in providing a decision maker with current information on the perceived threat, or in recalling the interceptor, will cause the interceptor to fly farther from its desired station. Once a C^3 system deficiency has contributed to initiating or prolonging the flyout of an interceptor in the wrong direction, the loss in air defense effectiveness will depend on the specific scenario being considered. The maximum degradation will occur when the interceptor is moved so far out of position that it is not able to participate in the defensive operation. In this case, the kill potential of the affected interceptor is lost to the force. Less severe degradations which may occur include delays in the earliest possible intercept time for a given interceptor due to the greater distance it must travel to reach the threat, and intercept delays due to lower interceptor speed capability due to the fuel wasted in flying out some distance in the wrong direction.

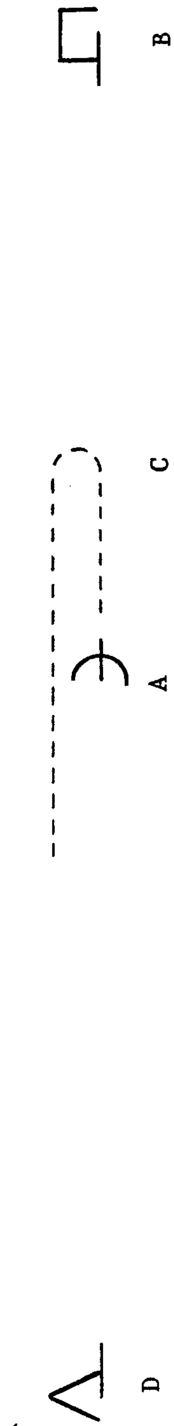

Figure 3. Interceptor Flies Out in Wrong Direction

To illustrate the quantitative effect of this problem, consider the following situation and the geometry shown in Figure 3. Assume that a target is detected at location B and the decision is made to intercept the target with a CAP since it is not responding to IFF. Assume that the aircraft is actually friendly and in voice contact with some force elements. If the C^3 system is occupied responding to the threat at location D, there may be a delay in reclassifying target B as friendly. If the delay in recognizing this error and correcting the interceptor's orders is 5 minutes, there will be a 5 minute delay in the time of intercept of threat D. If the threat is approaching at 500 knots, this will allow it to penetrate an additional 42 nmi. Depending on the specific situation, this may or may not represent a significant loss in effectiveness. If the threat is able to acquire targets and launch its weapons during that 42 nmi of travel, the C^3 deficiency has contributed to a step increase in the air defense problem.

INTERCEPTOR FLIES OUT ON NON-OPTIMUM PATH

When an interceptor flies out to engage a target, there is some optimum path which will close the intercept triangle in a minimum time with minimum fuel usage. In general, this path is a collision course to the target during the early phases of the intercept. The path may be a slightly modified collision course in order to improve the final interceptor positioning or make the success of the intercept less subject to threat maneuvers, but some optimum path will still exist to maximize the effectiveness of the intercept. Due to deficiencies in the C^3 system, the interceptor may not fly out along the optimum path and this can reduce the chances for a successful intercept.

The effects of the interceptor not flying out on the optimum path are expected to be a delay in the initiation of the engagement and a lower fuel state for the interceptor when the engagement is initiated. These effects are due to the fact that the non-optimum path requires the interceptor to fly farther prior to reaching the target. This requires

more time and more fuel. The causes of this problem include a number of types of errors and delays within the C^3 system. Any target tracking errors or delays in providing target data to the intercept controller will introduce errors into the command data provided to the interceptor. Once the interceptor is flying out on an incorrect course, any delay in communicating updated command data to the interceptor will result in the interceptor flying farther off the optimum intercept path. As the intercept proceeds, there is more and more time and fuel wasted as a result of this deviation from the optimum flight path.

Figure 4 illustrates this problem. The optimum intercept path is shown as a dashed line. The actual interceptor flight path that could result from target tracking errors and system response delays is shown as a solid line. The assumed error in interceptor heading is 20°. The figure shows heading changes at 2 minute intervals, although the results would be the same for more rapid or slower heading changes. For interceptor and target speeds of 540 knots, the intercept time for an optimum path is 19.25 minutes. For the non-optimum path shown, the intercept time is 20.09 minutes. Therefore, the effect of this flight path has been to delay the intercept by 0.84 minutes. Since the assumed heading error of 20° is believed to be quite severe, and the resulting intercept delay is relatively small, this problem is not believed to be a serious one compared to some of the others discussed in this memorandum.

INTERCEPTOR FLIES OUT TOO SLOWLY

When the C^3 system assigns an interceptor against a target, there will be some interceptor speed profile which will be most appropriate in terms of the time required for the intercept and the fuel used. However, the optimum speed profile may not be known to the C^3 system when the intercept is first initiated due to some aspect of the tactical situation. This, or an error in the command speed received by the interceptor, could cause the interceptor to initiate the flyout at a lower speed than will ultimately be required. Once the information indicating the

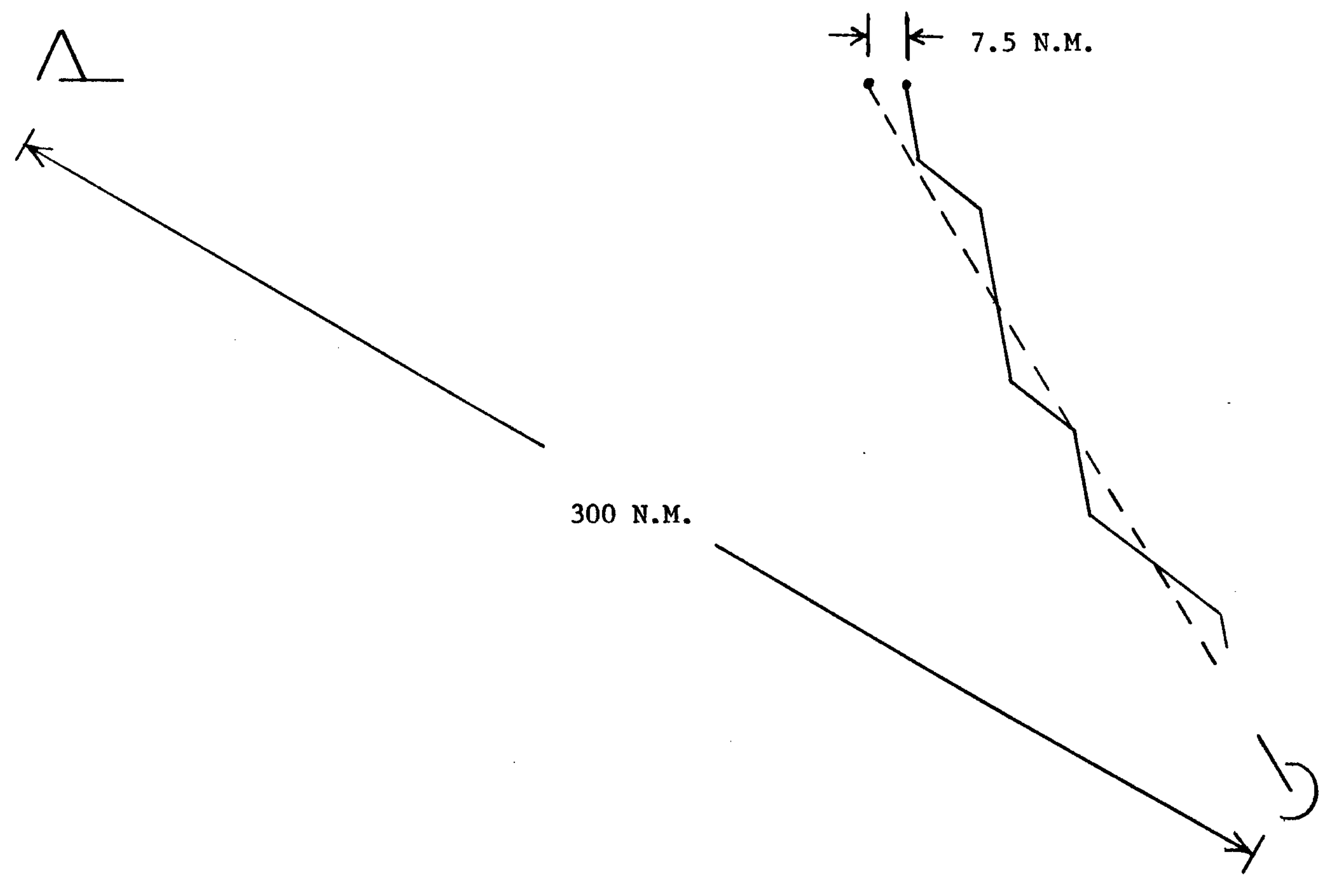

Figure 4. Interceptor Flies Out on Non-Optimum Path

desirability of a higher interceptor speed becomes available, any delay on the part of the C^3 system in recognizing this need or in transmitting new commands to the interceptor will result in a delayed intercept. Further, if the interceptor enters the engagement at too low a speed, it may be at a tactical disadvantage during combat with the enemy aircraft. Depending on the exact tactical situation, these factors may or may not have a significant influence on air defense effectiveness.

This effect can be illustrated as follows. Assume that a threat is approaching at 1.2 M and that an interceptor is flying out at 0.9 M to engage the threat. If at some point in time, the C^3 system decides it is appropriate for the interceptor to accelerate to 1.2 M, but there is a delay of T minutes in providing the new command speed to the interceptor, the time of the intercept will be delayed by 1/8 T. If the threat was approaching at 1.5 M and the initial interceptor flyout speed is 0.9 M, and the same delay of T minutes is introduced into the command to accelerate to 1.5 M, the resulting intercept delay will be 1/5 T. For a 5 minute delay, this means that the target will penetrate 15 nmi farther prior to being intercepted, which may or may not affect the air battle outcome.

INTERCEPTOR FLIES OUT TOO FAST

When the C^3 system initiates an intercept order, there is always the possibility that an error in the available data or in its interpretation will cause the interceptor to accelerate to too high a speed. Because of the high rate of fuel consumption for an interceptor using afterburner, this may result in the interceptor reaching a critical fuel state prior to the time it can initiate an engagement of the threat. This will result in a reduction in the expected effectiveness of the air defense operation.

The primary cause of this problem is expected to be errors in the C^3 system's evaluation of the threat's position and/or approach speed.

Once the interceptor has been ordered to fly out at supersonic speed, and data indicating that this is inappropriate becomes available, any delay in transmitting this information to the interceptor will further aggravate the problem. As a result of using too much fuel during flyout, the interceptor may not be able to initiate an engagement, or its ability to achieve maximum effectiveness with all weapons may be compromised by its low fuel state. No general quantitative relationship can be developed since it is so dependent on the specific situation. This problem is not expected to be a common one however, since the C^3 system is not likely to order the interceptor supersonic unless there is a high probability that it can successfully complete the intercept at that speed.

INTERCEPTOR NOT PROPERLY POSITIONED TO ENGAGE TARGETS

As an interceptor is being vectored out to intercept a threat, C^3 system deficiencies can cause the interceptor to be so positioned relative to the threat that the effective use of air-to-air weapons is prevented. As the interceptor closes on the threat, but prior to the time it detects the threat, any errors in commands received by the interceptor, and any delays in correcting the interceptor's flight path when it is wrong will result in less than optimum positioning. The magnitude of the positioning errors will depend on the vectoring errors, when they occur, and the exact geometry of the intercept. Once the interceptor has detected the target(s), it will attempt to improve its position relative to the threat and then initiate the engagement. Depending on the weapon system characteristics, the initial positioning error, and the reaction of the threat, the interceptor may or may not suffer a serious performance degradation. Under some circumstances (e.g., poor AI radar performance), the intercept may be missed completely, or the interceptor may be forced to convert to a rear hemisphere attack. Under other conditions, the interceptor may be so positioned that the number of forward hemisphere air-to-air missile launch opportunities is decreased from its maximum value and the resulting expected kill achievable by the interceptors is reduced.

This type of C^3 effect is illustrated in Figure 5. If, as a result of the control provided by the C^3 system, the interceptor is at location A when it detects the threat, it may be unable to launch any of its forward hemisphere missiles. If the tactical situation makes it impossible for the interceptor to convert to a rear hemisphere attack, no kills will be inflicted on the threat. If the C^3 system had placed the interceptor at location B, the interceptor would have been able to launch multiple missiles and could expect to kill several threat aircraft. In addition to positioning errors in the horizontal plane, the C^3 system can also influence interceptor kill potential through its ability to place the interceptor at the proper altitude to successfully engage the threat.

This effect can be brought about by a variety of factors. If the threat track data used by the C^3 system to compute the intercept course is in error, the commands sent to the interceptor will be incorrect. The longer the interceptor flies on an incorrect course, the more difficult it will be to achieve an optimum intercept position. When the C^3 system recognizes the need for a change in the interceptor's heading in order to improve its position relative to the threat, any delay in getting correct information to the interceptor can reduce overall effectiveness. This type of delay could occur if the communications link to the interceptor was jammed or busy with other transmissions.

An analysis of the extent to which this problem can influence weapon system effectiveness will not be presented here. Reference (b) presents the results of a sensitivity study of interceptor performance as a function of final positioning. It shows that effectiveness is sensitive to vectoring accuracy, with the amount of variation depending on the threat type and interceptor type. The relationship between the characteristics of the C^3 system and the positioning accuracy of the interceptor is currently being investigated. Preliminary results indicate that the expected positioning errors due to C^3 system deficiencies such as tracking errors and vectoring delays can be large enough to result in degraded interceptor performance. However, these errors are not so large as to cause a significant number of completely missed intercepts.

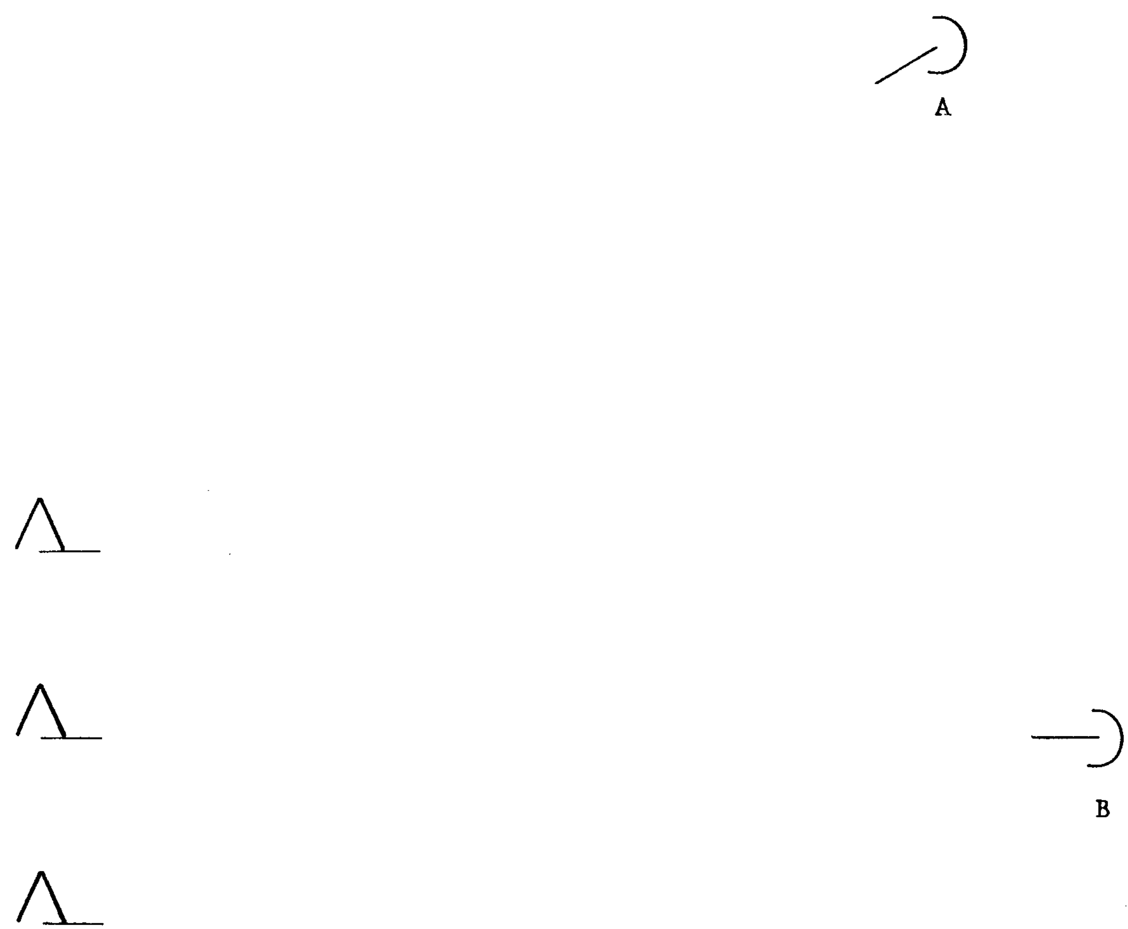

Figure 5. Interceptor Not Properly Positioned to Engage Targets

INTERCEPTOR ENGAGES NON-OPTIMUM TARGET

As an interceptor approaches its assigned target(s) and achieves detection, the pilot may be required to select some of the detected aircraft for engagement. When all the detected aircraft are threats of equal priority and other weapons systems are not simultaneously engaging, any of the targets could be selected with no effectiveness penalty. In other situations, however, the C^3 system can have an influence on air defense effectiveness by optimizing the selection of targets to be attacked. This will be true when specific targets are known to be higher priority, when the raid is being simultaneously attacked by multiple interceptors, or when one or more of the aircraft should not be attacked (it may be a friendly interceptor that the attacking interceptor is not aware of). In these situations, the failure of the C^3 system to properly control the engagement can have an effect on the expected air battle outcome.

This problem can be caused by any delay in the exchange of raid information. If some unit is aware of the relative priorities of each aircraft within a raid, but this information is delayed in reaching the attacking interceptor until after the engagement has begun, there will be a decrease in expected effectiveness. If the appropriate information is transmitted to the interceptor just prior to the beginning of the engagement, there is the possibility that the interceptor is not properly positioned to engage the optimum targets in the raid and an effectiveness decrease could also result.

Errors in information available within the C^3 system can also bring about this effect. A major contributor is expected to be navigation errors which cause confusion as to the specific targets that are being engaged by various weapon systems. This can result in a set of engagements that is less than optimum and is a direct result of C^3 system deficiencies.

Figure 6 illustrates this type of C^3 problem. Two interceptors, each carrying 4 air-to-air missiles, are approaching a group of 8 targets. Ideally, the C^3 system would assure coordination so that each interceptor engaged a different 4 targets. If each missile has a kill probability of P, the expected number of kills achieved is 8P. However, if the C^3 system does not coordinate the attack, effectiveness may be reduced. This could happen if the C^3 system does not inform the interceptors that another interceptor is also attacking, and the interceptors are not in contact with one another. Then, if both interceptors attack the same 4 targets, the expected kill is 4P(2-P). For a missile kill probability of .5, this represents a loss in expected kill of 25%.

INTERCEPTOR DELAYS IN ENGAGING TARGET

As an interceptor approaches the location of its assigned target(s) and achieves AI radar detection, it can generally be most effective if missile launch occurs as soon as possible. However, if the interceptor is not sufficiently aware of the tactical situation, which can lead to uncertainty as to whether the detected target is a threat that should be attacked, the interceptor may delay the missile launch. By the time the interceptor decides to engage the target, his position may limit the number of missile launches that are possible and so the interceptor's kill potential is reduced.

Figure 7 illustrates one possible situation that could cause this to occur. Assume that interceptor A has attacked threat group B and is breaking off to the right. At the point shown in Figure 7, interceptor C has just achieved radar detection of interceptor A and threat B. If interceptor C is aware of the tactical situation, he can rapidly determine which target is the threat and initiate the engagement. However, if interceptor C is not communicating with interceptor A or the command and control system (but is aware that interceptor A is in the area), there may be a problem. Interceptor C may not be certain which of the two radar tracks is friendly, and therefore initial missile launch is likely

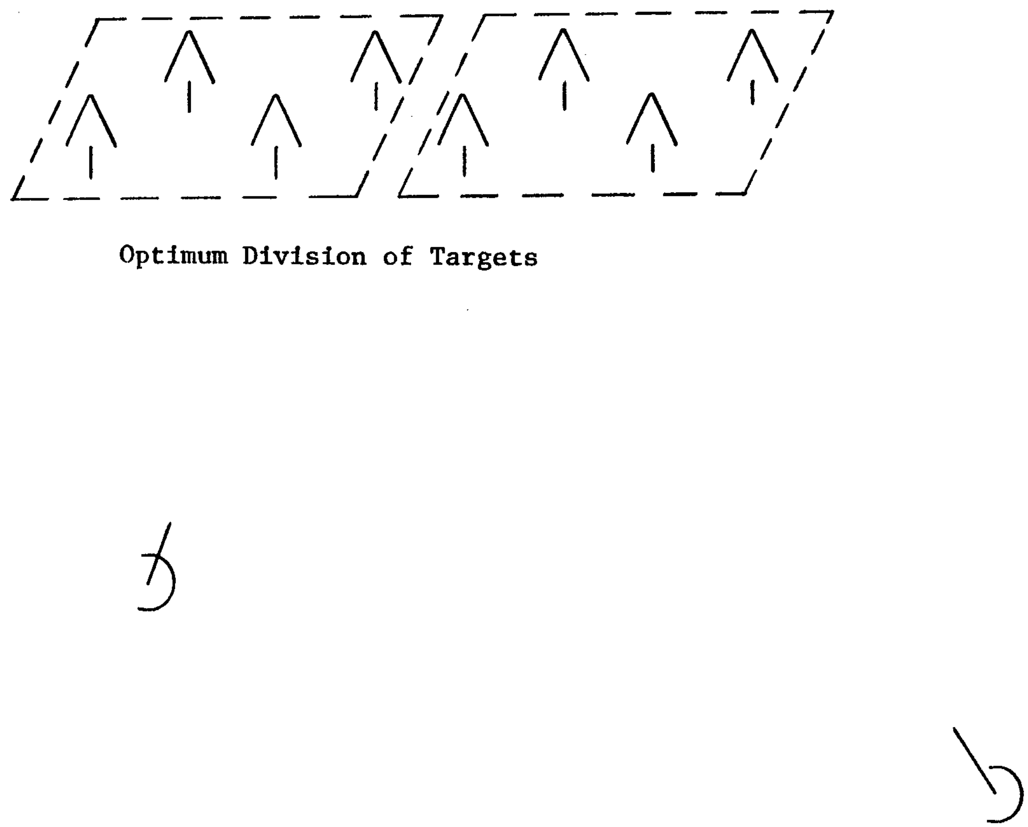

Figure 6. Interceptor Engages Non-Optimum Target

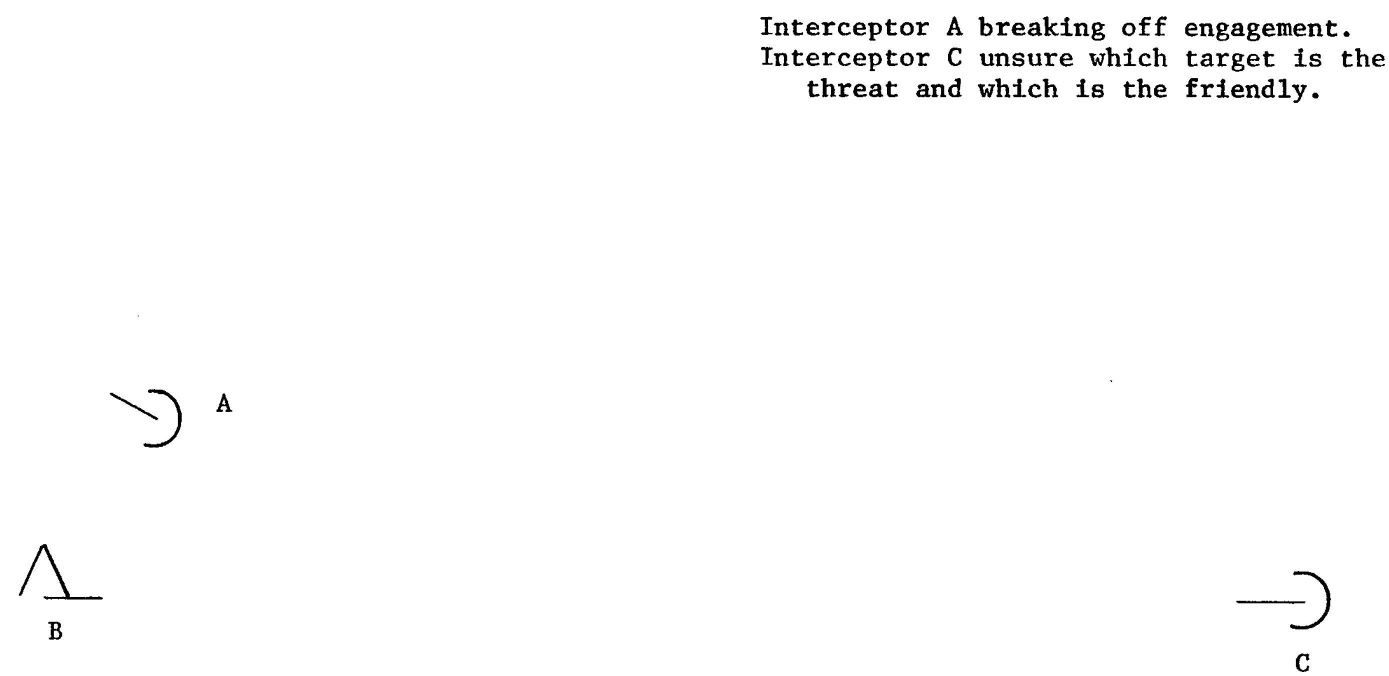

Figure 7. Interceptor Delays in Engaging Target

to be delayed until the pilot can assure himself that he is not engaging a friendly aircraft. By that time, interceptor C may have closed on the threat to the point that no missile launches are possible.

There are a number of C^3 problems that can cause this situation to occur. Among these are target tracking errors and surveillance system navigation errors which could introduce uncertainty into the tactical picture available to the interceptor. In addition, communication problems which prevent the interceptor from receiving current tactical data can also bring this situation on. To the extent that this introduces doubt or confusion into the interceptor pilot's mind, he may not begin to engage his target at the earliest possible time. Depending on the specific geometry of the situation, this may have a significant influence on the effectiveness of the interceptor's attack. The greater the delay before the pilot acts, the more likely it is that launch opportunities will be lost. Under most conditions, each lost missile launch opportunity represents a decrease in expected air defense effectiveness.

The potential effectiveness impact of this C^3 problem is highly variable. Reference (b) contains data that is illustrative of the effectiveness sensitivity. In one case analyzed in the reference, a 45 second delay in initiating an attack can reduce the expected number of targets killed by 60%. Although this is a severe case, it does show that this type of C^3 problem can have a significant influence on interceptor effectiveness.

INTERCEPTOR FAILS TO COMPLETE AN ENGAGEMENT

Once an interceptor has begun the engagement of its assigned targets, it will generally have a specific time interval within which to employ its weapons in order to achieve maximum effectiveness. Any time that the interceptor, due to uncertainty about the tactical situation,

breaks off the engagement earlier than is necessary, there will be a reduction in the effectiveness of its attack. The ordnance not used by the interceptor represents a wasted air defense capability. It is the responsibility of the C^3 system to provide each interceptor with sufficient and timely tactical data to allow the interceptor to perform to its maximum capability.

The development of this kind of situation is illustrated in Figure 8. Assume that interceptor A has launched several forward hemisphere missiles against the threat group and is now in a position to turn in behind the threat group. If the interceptor initiates the turn it will be able to attack one or more threats with AIM-9 missiles. If the interceptor pilot is confident that this maneuver will not subject him to a significant risk of being attacked by other friendly forces, he can complete the turn and finish his engagement. This will maximize the effectiveness of his attack. However, if the interceptor pilot is not fully aware of the tactical situation, he may assess the potential risk of attack as being too high. Consequently, he will maintain a heading that will take him clear of the threat group where the danger of coming under friendly fire is minimal.

He might make this decision if he had any reason to believe that the threat group was about to come under attack by another interceptor aircraft or by surface-to-air missiles. With proper coordination by the C^3 system, the interceptor could be expected to take appropriate action in any given situation. When the C^3 system is not performing properly and the interceptor does not have the necessary data, there is always the chance that the pilot will make an incorrect decision to terminate the engagement and therefore have an adverse effect on the number of kills achieved.

This type of problem can be brought about by any C^3 system characteristic which causes an interceptor pilot to be uncertain about the identity of the targets he is attacking, or about the positions or

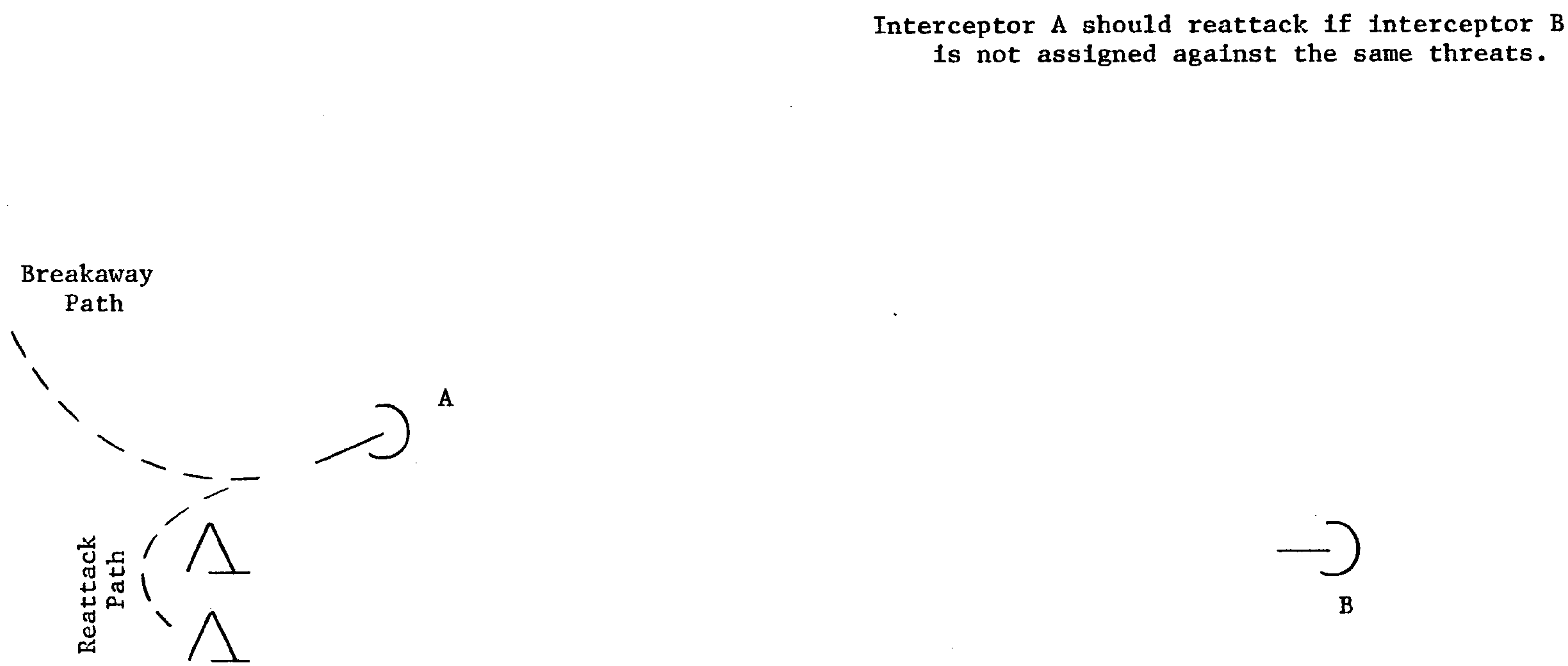

Figure 8. Interceptor Fails to Complete an Engagement

assignments of other friendly weapon systems in his general vicinity. The confusion can result in the pilot terminating the engagement before it is necessary. Whenever this occurs, the number of targets killed is less than the number that could have been killed if the attack had been continued, and so the C^3 system was ultimately responsible for a reduction in the effectiveness of the air defense forces.

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SUMMARY

The previous section of this memorandum discussed in detail the various ways in which degradations in C^3 performance can affect the performance of interceptor aircraft in the fleet air defense role. The discussion was largely qualitative although quantitative illustrations of specific problem areas were presented where possible. The objective of this discussion was to describe the interaction mechanisms through which C^3 systems influence the capability of interceptor aircraft in anti-air warfare. Because of the complicated nature of these interaction mechanisms, it is impossible to provide a brief summary of these C^3/AAW relationships. This section summarizes the insights into the C^3/AAW problem as brought out in the previous section and identifies those C^3 factors which are currently felt to have the greatest impact on air defense effectiveness.

GENERAL C^3/AAW RELATIONSHIPS

As discussed earlier in this memorandum, there are a large number of C^3 deficiencies which can adversely affect the performance of interceptor aircraft in their fleet air defense mission. These C^3 deficiencies can be logically grouped into two general categories. These categories are (1) the introduction of delays into C^3 functions, and (2) the introduction of errors into the information needed to carry out the C^3 functions. Whenever the C^3 system exhibits either or both of these deficiencies, there are 10 effects that this can have on the actions of interceptor aircraft. Each of these 10 effects has been described in detail in the previous section. When the C^3 system brings about one or more of these effects, there may or may not be a reduction in air defense effectiveness. This will depend on the details of the tactical situation. The following paragraphs will provide some observations on these cause/effect relationships.

Intercept Delays

Of the 10 effects which C^3 performance can have on interceptor aircraft, 4 can be translated into delays in the time at which the interceptor is able to begin its attack on the enemy. These 4 effects are:

- Late initiation of interceptor flyout
- Interceptor flies out in wrong direction
- Interceptor flies out on non-optimum path
- Interceptor flies out too slowly

Any or all of these problems can be caused by delays or errors within the C^3 system. The mechanisms through which the C^3 system can influence the time at which the intercept occurs has been discussed previously. In many cases, it is probable that the intercept delay which can be attributed to the C^3 system will not influence the force's air defense effectiveness. There are other cases, however, where the time of intercept will impact effectiveness. For example, when the intercept time provided for by a perfect C^3 system is early enough to allow a bomber to be killed prior to ASM launch, but the intercept time achieved with the actual C^3 system is after the ASMs have been launched, there is a clear loss in air defense effectiveness due to the performance of the C^3 system. The intercept delay experienced would be the result of the delays brought about by each of the 4 effects discussed above.

In order to analyze these interactions between C^3 performance and air defense effectiveness, it is clearly necessary to evaluate not only the length of the time delays involved, but also the time at which the delay occurred in the air battle. The result of a given delay will be different for each interceptor/target engagement considered. Further, any given C^3 system problem can bring about multiple effects and each will have a different quantitative influence on air defense effectiveness. For these reasons, generalizations on the importance of these C^3 effects on interceptors are difficult to make. However, the following

observations are appropriate relative to the 4 C^3 effects discussed above. The intercept time delay resulting from any one of these effects will be less than or equal to the delay within the C^3 system which caused the intercept delay. For C^3 delays of 2 or 3 minutes, which would seem reasonable when a C^3 system became overloaded, the delays in the time of threat intercept might be less than a minute. This would not be expected to seriously degrade air defense effectiveness. However, the above does not consider the possible additive effects of the delays. It is likely that in a given situation C^3 system deficiencies will cause several of these effects, and the total delay in the time of intercept will be greater than the delays within the C^3 system. The combined effects of these problems have not yet been determined.

Reduced Interceptor Kill Effectiveness

Delays and/or errors within the C^3 system can cause a degradation in certain performance characteristics of a controlled interceptor which reduce its kill effectiveness. Seven of the 10 C^3 effects on interceptor aircraft fall into this category. These effects are:

- Interceptor flies out in wrong direction
- Interceptor flies out on non-optimum path
- Interceptor flies out too fast
- Interceptor not properly positioned to engage targets
- Interceptor engages non-optimum target
- Interceptor delays in engaging target
- Interceptor fails to complete an engagement

Whenever the C^3 system brings about one or more of these effects, a given interceptor may not be able to employ all of its air-to-air missiles in an effective manner. This may be due to several factors. Among these factors are a low interceptor fuel state, poor interceptor position relative to the target at missile launch, wasteful use of missiles against low value targets, and reduction in the number of

missiles launched due to the pilot's uncertainty about the tactical situation. Through these mechanisms, any deficiency in C^3 system performance will bring about a reduction in expected air defense effectiveness.

The previous section discussed each of the above C^3 effects in detail and their potential impact on air defense effectiveness. In most cases, it is particularly difficult to quantify the loss in air defense effectiveness for this group of effects. This is believed to be due to the nature of the interaction mechanisms. The effects of a low interceptor fuel state can be analyzed, but, in practice, will be highly variable due to assumed fuel reserve requirements, tanker availability, etc. The loss in missile launch opportunities resulting from pilot confusion is difficult to quantify because of the uncertain relationship between the information available to the pilot, his resulting perception of the changing tactical situation, and his actions based on that perceived situation. The interaction mechanism for which a thorough analysis has been performed is the positioning of the interceptor by the C^3 system in order to maximize its kill potential against the assigned targets. As summarized previously and analyzed in reference (b), the C^3 system can have a significant effect on an interceptor's kill potential by virtue of its ability to place the interceptor in an advantageous missile launch position relative to an air raid. It appears that typical C^3 system errors of this type will result in somewhat degraded interceptor performance and should be considered in any C^3 effectiveness analysis. Further, several of the above-mentioned effects can take place simultaneously and the additive effect on the number of kills that an interceptor achieves may be very significant. These combined effects have not yet been analyzed.

Resource Allocation Errors

The other type of problem that can be brought about by delays and errors within a C^3 system is the inefficient allocation of defensive

resources. Of the 10 C^3 effects on interceptors, only one falls into this category:

- Sub-optimum allocation of interceptors to targets

This can take place when the C^3 system does not take advantage of all of the potentially available information to make the best use of the limited number of interceptors available to counter a large enemy attack. When this occurs, some of the force's interceptors are committed in excessive numbers against part of an attacking force while another part of the attack is allowed to approach task force center unopposed.

As discussed in the previous section, this type of problem can have a significant impact on air defense effectiveness. The magnitude of the problem will depend on the configuration of the individual air raid and the extent to which the C^3 system fails to provide accurate and timely information to a decision maker. This C^3 effect is potentially the most serious individual degrading factor in friendly force air defense effectiveness. It is of major concern not only because the total number of enemy kills is reduced, but also because a portion of an enemy air raid may be allowed to penetrate towards task force center with minimum disruption of its timing and formation. The result may be the saturation of a sector of the inner defense zone.

Although this interaction appears to be one of the most important in relating the performance of the C^3 system and the air defense effectiveness achieved, it may not come into play as often as some of the others discussed in this memorandum. It is not clear that it is always possible for the C^3 system to expect to gather the data that are needed to properly allocate interceptors in the dense radar countermeasures environments that are expected.

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SUMMARY OF SIGNIFICANT INTERACTION MECHANISMS

Based on the effectiveness evaluations discussed in this memorandum, it appears that the single most critical effect that C^3 system performance can have on interceptor effectiveness is to provide for the proper allocation of interceptors against an air raid. Once this allocation function is completed, the capability of the C^3 system to provide each interceptor with accurate control instructions and an adequate assessment of the tactical situation will further affect the force's air defense capability. Additional quantitative analysis will be required before the overall importance of these interaction mechanisms can be fully appreciated. Finally, the C^3 system performance can affect the time at which intercepts occur, but this appears to be the least significant form of effectiveness degradation.

The ranking of C^3 effects just presented is largely a qualitative evaluation of their importance although it is based on a limited amount of quantitative data. There is a critical need to generate more quantitative data showing the interactions between C^3 system performance and interceptor effectiveness. This must be done for a variety of scenarios in order to assure that sufficient data are available to draw valid conclusions. Once the most important C^3/AAW interaction mechanisms have been identified, educated decisions can be made on the proper way of modeling these interactions and fully investigating their cumulative effects.

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